"Heat Transfer Augmentation using Alufer Tube"

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ABSTRACT

Heat transfer enhancement has been always a significantly interesting topic in order to develop high efficient, low cost, light weight, and small heat exchangers. The energy cost and environmental issue are also encouraging researchers to achieve better performance than the existing designs. Two of the most effective ways to achieve higher heat transfer rate in heat exchangers are using different kinds of inserts and modifying the heat exchanger tubes. The ALUFER tube is the technology behind the advanced heat transfer design. The tube is constructed from an inner (fireside) aluminum alloy finned surface, die-fitted within an outer steel tube, providing exceptional heat exchange characteristics. This finned structure opens opportunities for new heat exchanger designs heat exchangers are very important to the overall efficiency, cost, and size of the system. Thermal conductivity of the ALUFER tube is significantly greater than that of carbon steel. Internal finned surface of the ALUFER tube enlarges the heat exchange surface three-fold. Inner surface of the tube is divided into multiple flow channels to create maximum turbulence and heat transfer.

Keywords: *Heat transfer Enhancement, passive technique, internally finned tube, Alufer tube, counter flow HE., LMTD ,etc*

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1. INTRODUCTION

The heat is defined as the form of energy which can be transferred from one system to another system across their boundaries due to temperature difference existing between the two systems. The amount of heat energy transferred across the system can be determine by the application of First law of thermodynamics involving work and other forms of energies. During heat transfer, it is observed that the heat energy always flows in direction from higher temperature medium to lower temperature medium and the transfer of heat energy stops once both the medium reach to their equality of temperature. Several heat transfer enhancement (HTE) techniques have been used in many engineering applications such as nuclear reactor, chemical reactor, chemical process, automotive cooling, refrigeration and heat exchanger etc.

Heat exchangers are used in different processes ranging from conversion, utilization & recovery of thermal energy in various industrial, commercial & domestic applications. Some common examples include steam generation & condensation in power & cogeneration plants; sensible heating & cooling in thermal processing of chemical, pharmaceutical & agricultural products; fluid heating in manufacturing & waste heat recovery etc. Increase in Heat exchanger's performance can lead to more economical design of heat exchanger which can help to make energy, material & cost savings related to a heat exchange process. The need to increase the thermal performance of heat exchangers, thereby effecting energy, material & cost savings have led to development & use of many techniques termed as Heat transfer Augmentation. These techniques are also referred as Heat transfer Enhancement or Intensification. Augmentation techniques increase convective heat transfer by reducing the thermal resistance in a heat exchanger. Internal finned type of passive heat transfer augmentation techniques have shown significantly good results in past studies.

Enhanced hat transfer can be used for three purposes:

(1) To make heat exchangers more compact in order to reduce their overall volume, and possibly their cost,

(2) To reduce the pumping power required for a given heat transfer process, or

(3) To increase the overall UA value of the heat exchanger. A higher UA value can be exploited in either of two ways:

(a) To obtain an increased heat exchange rate for fixed fluid inlet temperatures, or

(b) To reduce the mean temperature difference for the heat exchange; this increases the thermodynamic process efficiency, which can result in a saving of operating costs.

1.1 The Enhancement Techniques

Enhancement techniques can be separated into two categories: passive and active.

1. Passive methods require no direct application of external power. Instead, passive techniques employ special surface geometries or fluid additives which cause heat transfer enhancement. On the other hand,
2. Active methods such as electromagnetic fields and surface vibration do require external power for operation
3. Compound techniques: This technique is a combine form of more than one above mentioned technique and basically used with a purpose to get the higher performance from heat exchanger.

Heat exchangers with extended surfaces are widely used whenever heat is to be exchanged between a medium that transports heat well (e.g. liquid, liquid with phase transition) and one that does not (e.g. gas with small density). On the side of the medium transporting heat poorly, the heat-transferring surface is enlarged by an arrangement of fins or other elements such as pins or needles. These elements for enlarging the surface can be attached up to a relatively great height to the surface, or they can be small and formed from the tube material itself. Fins can be arranged in tubes on both the outside and the inside and mainly transversely or along the sleeve shaft axis. From among the great abundance of possible arrangements, only tubes with inside fins, arranged along the tube axis will be considered here.

Special surface geometries provide enhancement by establishing a higher hA per unit base surface area. Clearly, there are three basic ways of accomplishing this:

1. Increase the effective heat transfer surface area (A) per unit volume without appreciably changing the heat transfer coefficient (h). Plain fin surfaces enhance heat transfer in this manner.

2. Increase h without appreciably changing A. This is accomplished by using a special channel shape, such as a wavy or corrugated channel, which provides mixing due to secondary flows and boundary-layer separation within the channel. Vortex generators also increase h without a significant area increase by creating longitudinally spiraling vortices exchange fluid between the wall and core regions of the flow, resulting in increased heat transfer.

3. Increase both h and A. Interrupted fins (i. e. offset strip and louvered fins) act in this way. These surfaces increase the effective surface area, and enhance heat transfer through repeated growth and destruction of the boundary layers.

2. LITERATURE REVIEW

Researchers has reported various internal finned tube by experimental validation, by Numerical modeling to achieve high heat transfer rate with minimum pressure drop and also for minimizing flow resistance increase when developing novel heat augmentation technique. Different heat transfer enhancers are reviewed. They are (a) fins and micro fins, (b) porous media, (c) large particles suspensions, (d) nano fluids, (e) phase-change devices, (f) flexible seals, (g) flexible complex seals, (h) vortex generators, (i) protrusions, and (j) ultra high thermal conductivity composite materials[13]. Most of heat transfer augmentation methods presented in the literature that assists fins and micro fins in enhancing heat transfer are reviewed. It is found that not much agreement exists between works of the different authors regarding single phase heat transfer augmented with micro fins. However, too many works having sufficient agreements have been done in the case of two phase heat transfer augmented with micro fins; there are still many conflicts among the published works about both heat transfer enhancement levels and the corresponding mechanisms of augmentations. In addition, this paper describes a well-modeled passive enhancement method. Many recent works related to passive augmentations of heat transfer using vortex generators, protrusions, and ultra high thermal conductivity composite material are reviewed. Finally, theoretical enhancement factors along with many heat transfer correlations are presented**.**

A Dewan & P Mahanta et al[1] commented on Heat transfer augmentation techniques (passive, active or a combination of passive and active methods) are commonly used in areas such as process industries, heating and cooling in evaporators, thermal power plants, air-conditioning equipment, refrigerators, radiators for space vehicles, automobiles, etc. Passive techniques, where inserts are used in the flow passage to augment the heat transfer rate, are advantageous compared with active techniques, because the insert manufacturing process is simple and these techniques can be easily employed in an existing heat exchanger. In design of compact heat exchangers, passive techniques of heat transfer augmentation can play an important role if a proper passive insert configuration can be selected according to the heat exchanger working condition (both flow and heat transfer conditions). Author gave reviews on progress with the passive augmentation techniques in the recent past and will be useful to designers implementing passive augmentation techniques in heat exchange. Twisted tapes, wire coils, ribs, fins, dimples, etc., are the most commonly used passive heat transfer augmentation tools.

Heat transfer performance of T-section internal fins in a circular tube has been experimentally investigated by Islam, A., & Mozumder, A. K. [2] Flows having Reynolds number ranging from 2x10^4 to 5x10^4 for both smooth and finned tubes are examined to measure data, heat transfer coefficient, Nusselt number and friction factor by the author and conclude that the heat transfer coefficient was 2 times higher than those for smooth tube for similar flow conditions.

Experimental investigations have been performed by Saad A. El-Sayed et al. to determine the detailed module-by-module pressure drop and heat transfer coefficient of turbulent flow inside a circular finned tube. The tubes are provided with longitudinal fins continuous or interrupted in the stream wise direction by arranging them both in a staggered and in-line manner. Experiments are carried out for two different fin geometries, with two numbers of fins. The thermal boundary condition considered here, is a uniform heat flux. The module-by-module heat transfer coefficient is found to vary only in the first modules, and then attained a constant thermally periodic fully developed value after eight to twelve modules. The results also showed that in the periodic hydrodynamic fully developed region. Author concludes the tube with continuous fins produces a greater value of the heat transfer coefficients than that the tube with interrupted fins, especially through a high range of Reynolds number ($5 \times 10^4 > Re > 2 \times 10^4$). It was found that the fins efficiency is greater than 90 percent

In Hoval and cleaver brooks boiler brochure [3][4]design of Alufer tube is explained. The tube is constructed from an inner aluminum alloy finned surface, die-fitted within an outer steel tube, providing exceptional heat exchange characteristics. It also comments on optimized efficiency, size reduction, reduction in cost of the heat exchanger. Information about boiler using alufer tube is given that The ClearFire®-V boiler [3] has a high-quality, steel combustion chamber with ALUFER tubes. The single pass down fire arrangement ensures the maximum heat exchanger effectiveness and provides an inverse efficiency characteristic, making the ClearFire-V most efficient at reduced firing rates. The high-turndown, modulating burner minimizes short cycling and allows the boiler to operate at peak efficiency.

3. METHODOLOGY

a) Literature survey for related heat transfer augmentation technique presented by different researcher.
b) Selection of the optimized designed for the heat exchanger tube
c) Selection of the optimum material
d) Understanding the experimental setup needed for the project.
e) observations and calculation of experimental data.
f) Comparing the results with conventional heat exchanger

Experimental test sections and set up used is as follows. The experimental setup consists of heat gun which is the source of the hot gas, flow control valve to maintain the measured quantity of flow through the test section, measuring jar to measure the mass flow rate. Alufer tube is used for test section having outer diameter of 75mm. A uniform heat flux condition is created by allowing hot air which is heated by heat gun/ heater. Electric power supply to heater is controlled by dimmer stat of 260 v capacity. Alufer tube is placed inside shell and water is allowed to flow in opposite direction of air flow.

Fig 1: test setup

Actual alufer tube.

Fig 2: Alufer tube section used in test setup

Data reduction:

For calculation of coefficient of convective heat transfer (h), LMTD method can be employed with counter flow heat exchanger. In this type of heat exchanger, both the fluids flow in opposite direction fig (3) shows the counter flow heat exchanger.[12] Wall of separation should possess high thermal conductivity (K) values. First law of thermodynamics applied to heat exchanger.

According to Steady flow energy equation:

(ΔH)hot fluid +((ΔH)cold fluid = 0

Rate of enthalpy decrease of hot fluid = Rate of enthalpy increase of cold fluind

Hence, energy balance equation or heat balance equation is given by

$m_h C_{ph}(T_{hi} - T_{he}) = m_c C_{pc}(T_{ce} - T_{ci})$ ....watt

Where,

m_h = mass flow rate of hot fluid in kg/sec

C_{ph} = specific heat capacity of hot fluid in J/kg-kelvin

m_c = mass flow rate of cold fluid in kg/sec

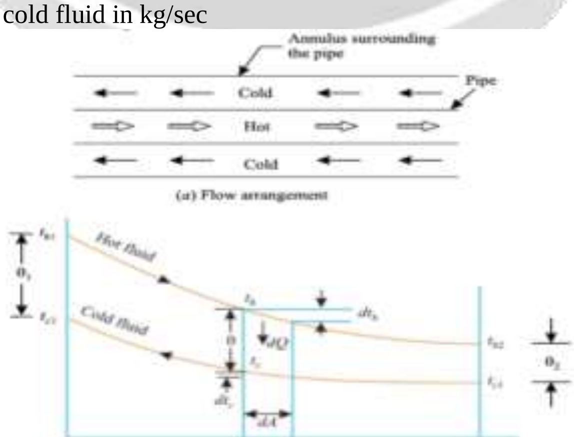

Fig 3: Counter flow heat exchanger[12]

LMTD (log mean temperature difference)[12]:

$$\theta_1 = t_{hi} - t_{co}$$
$$\theta_2 = t_{ho} - t_{ci}$$

$$\therefore \theta_m = \frac{\theta_1 - \theta_2}{ln\left(\frac{\theta_2}{\theta_2}\right)} \quad (1)$$

$$Q = UA\theta_m \quad (2)$$
$$Q = m_c\, C_{pc}(T_{ce} - T_{ci}) \quad (3)$$

Equate Eq. (3) wit Eq. (2) to find Overall convective heat transfer coefficient (U)

Overall convective heat transfer coefficient (U):
1. for conventional tube

$$\therefore U = \frac{1}{\frac{1}{h_h} + \frac{ln\left({}^{r_o}/_{r_i}\right)}{2\pi LK} + \frac{1}{h_w}} \quad (4)$$

2. for alufer tube

$$\therefore U = \frac{1}{\frac{1}{h_h} + \frac{ln\left({}^{r_i}/_{r_h}\right)}{2\pi LK} + \frac{ln\left({}^{r_o}/_{r_i}\right)}{2\pi LK} + \frac{1}{h_w}} \quad (5)$$

Where
r_h=hydraulic radius

$$D_h = \frac{4 \times Area(A_c)}{Perimeter(p)} \quad (6)$$

Reynolds number: ratio of inertia forces to viscous forces in the fluid

$$R_e = \frac{inertia\ forces}{viscus\ forces} = \frac{\rho v D}{k} \quad (7)$$

At large Re numbers, the inertia forces, which are proportional to the density and the velocity of the fluid, are large r elative to the viscous forces; thus the viscous forcs cannot prevent the random and rapid fluctuations of the fluid (turbulent regime).
The Reynolds number at which the flow becomes turbulent is called the critical Reynolds number.

Prandtl number: is a measure of relative thickness of the velocity and thermal boundary layer

$$Pr = \frac{molecular\ diffusivity\ of\ momentum}{molecular\ diffusivity\ of\ heat} = \frac{v}{\alpha} = \frac{\mu C_p}{k} \quad (8)$$

Nusselt number: Empirical correlations for predicting Nusselt number for cylinder [12] proposed as follows:

$$Nu = C(R_e)^n (P_r)^{0.333} \quad (9)$$

R_e	c	N
0.4 to 4	0.989	0.33
4 to 40	0.911	0.385
40 to 4×10^3	0.683	0.466
4×10^3 to 4×10^4	0.193	0.618
4×10^4 to 4×10^5	0.026	0.805

Overall Nusselt number (Nu) calculated by

$$Nu = \frac{h_w \times L_c}{K} \quad (10)$$

Calculate h_W by equating Eq.(9) & Eq.(10) for of both the tubes (conventional & alufer tube)

Put the value of h_W in Eq.(4) &Eq.(5) and calculate h_h for of both the tubes (conventional & alufer tube)
Now compare (h_h) for alufer tube and (h_h) for conventional tube.

4. CONCLUSION

It concluded that the quantitative comparison has been made for both finned and smooth tube. The heat transfer is enhanced as high as 2 times in the finned tube compared to smooth counterpart in the Reynolds number range from 2.0×10^4 to 5.0×10^4.

The heat transfer for turbulent flow in circular tube with inline arrangement of longitudinal fins on the inside surface is investigated experimentally. The experiment performed to determine the detailed heat transfer characteristics from which average nusselt number can be determined which gives information about heat transfer coefficient for the alufer tube, and compared with the coefficient of conventional tube heat exchanger.

The studies have proved that the alufer tube with internal finned structure can significantly enhance the heat transfer by increasing the near-wall turbulent mixing level by producing strong vortex flows, and therefore enhance the convective heat transfer

5. NOMENCLATURE

D	Inner diameter of the finned tube (m)	*LMTD*	Log mean temperature difference
L	Length of the test section (m)	*Q*	Input heat flux (W/m^2)
SA	Inside heat transfer area (m^2)	*V*	Velocity of fluid (m/s)
T_{wi}	Temperature water inlet (℃)	*μ*	Dynamic viscosity of air ($N.s/m^2$)
T_{wo}	Temperature water outlet (℃)	*ρ*	Density of air (kg/m^3)
T_{Ai}	Temperature hot air inlet (℃)	*F*	Finned tube
T_{Ao}	Temperature hot air outlet (℃)	*Nu*	Nusselt number based on nominal tube diameter=(hl_c/k)
t	Time required to collect water	*Pr*	Prandtl Number=$\mu c_p/k$
v	Quantity of water flowing for time 't' (ml)	*Re*	Reynolds Number based on inside diameter=$\rho vD/\mu$
Cp_{air}	Specific heat capacity of air (J/kg ℃)	*H*	Heat transfer co-efficient (W/m^2℃)
Cp_{water}	Specific heat capacity of water (J/kg ℃)	*K*	Thermal conductivity of air (W/m^2℃)
h	Heat transfer co-efficient (W/m^2℃)	*U*	Overall heat transfer coefficient W/m^2℃)
k	Thermal conductivity of air (W/m^2℃)		

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